Department of Materials Science and Engineering
Henry Samueli School of Engineering and Applied Science
University of California at Los Angeles

MSE 104, Fall 2017
Quiz No. 2, November 29, 2017

Name: Simon Rufer

Question	Points
1 (20 pts)	20
2 (25 pts)	25.
3 (25 pts)	25
4 (30 pts)	30
Total	100.

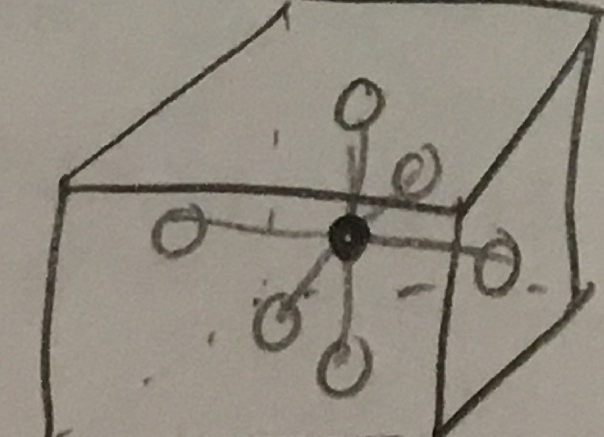
Show all work and must include units to receive full credit.
Check that all parts are answered.

1. (a) Will each of the following elements act as a donor (n-type) or acceptor (p-type) when added to the indicated host semiconductor. Assume impurity atoms substitute for the host atoms. Hint: In compound semiconductors, the impurity atom replaces the host atom closest to it. (10 pts)

Impurity	Host semiconductor	
P	Si	n-type
Ga	Ge	p-type
Se	InSb	n-type
In	CdS	n-type
As	ZnTe	p-type

(b) Why is the permanent dipole in $BaTiO_3$ lost when it is in the cubic phase? (5 pts)

The titanium atom in cubic phase sits centrally in the atom, with its oxygens surrounding it symmetrically. Thus, there is no net dipole



(c) Would you expect $SrTiO_3$ to have a permanent dipole as $BaTiO_3$? (Yes or no answer is sufficient) (5 pts)

yes

2. (a) Name all polarization mechanisms possible in NaCl? (Hint: possibilities are electronic, ionic and orientation polarization). (5 pts)

Electronic and Ionic

(b) A charge of 2.0 x 10^{-10} C is to be stored on each plate of a parallel plate capacitor having an area of 650 mm^2 and a plate separation of 4.0 mm. Determine the following – remember to include units.

i. What electric field must be applied if a material with dielectric constant of 4.5 is positioned within the plates? (4 pts)
ii. What is the capacitance of the capacitor in part (i)? (4 pts)
iii. What is the polarization for the capacitor in part (i) (4 pts)
iv. What is the surface charge density (also referred to as the dielectric displacement) for the capacitor in part (i). (4 pts)
v. Which material will have the higher dielectric constant, pure SiO_2 or MgO-SiO_2? (4 pts) (No explanation necessary)

$Q = 2.0\times10^{-10}$ C $\quad Q = CV \quad A = 650\,mm^2 = 6.5\times10^{-4}\,m^2$

$d = 4.0\,mm = .004\,m$

i) $\epsilon_R = 4.5$

$C = \frac{\epsilon_R \epsilon_0 A}{d} \quad Q = CV \quad E = V/d$

$Q = CEd$

$Q = \frac{\epsilon_R \epsilon_0 A E d}{d}$

$E = Q/(\epsilon_R \epsilon_0 A)$ $\quad$ $E = 7726\ V/m$

ii) $C = \frac{\epsilon_R \epsilon_0 A}{d} = \frac{(4.5)(8.85\times10^{-12})(6.5\times10^{-4})}{0.004} = 6.47\times10^{-12}\ F$

iii) $P = \epsilon_0(\epsilon_R - 1)E$

$P = 2.39\times10^{-7}\ C/m^2$

$D = \epsilon E = \epsilon_0 E + P$

$\epsilon_R \epsilon_0 E = \epsilon_0 E + P$

$P = \epsilon_R \epsilon_0 E - \epsilon_0 E$

$P = \epsilon_0 E(\epsilon_R - 1)$

iv) $D = \epsilon_R \epsilon_0 \cdot E$

$D = 3.08\times10^{-7}\ C/m^2$

v) ~~ϵ_R ... ϵ_R polymer~~

$P = \epsilon_0 E(\epsilon_R - 1)$

→ the one with greater polarization

MgO-SiO_2

SiO_2: Electronic

MgO-SiO_2: Electronic, ionic → MgO-SiO_2 has greater polarization

2

(a) GaP has a band gap of 2.25 eV, over what wavelength region of visible light will it be transparent? Visible light is from 400nm to 700 nm. (5 pts)

$E = h\nu$ $\quad c = \nu\lambda$

$2.25 eV \leq (4.13\times10^{-15} eV\text{-}s)(\nu)$

$\nu \geq 5.45\times10^{14}$ Hz

$\lambda \leq c/\nu \implies \lambda \leq 5.507\times10^{-7}$ m

→ GaP will absorb light with wavelength less than 550.7 nm.

There fore it is transparent to wavelengths $550.7nm < \lambda < 700nm$

+5

3 (b) At room temperature, the electrical conductivity and the electron mobility for Al are 3.8 x 10^7 (Ω-m)$^{-1}$ and 0.0012 m^2/V-s, respectively. (20 pts)
(i) Calculate the number of free electrons per m^3 for Al at room temperature.
(ii) What is the number of free electrons *per aluminum atom*? Assume a density of 2.7 g/cm^3, and the atomic weight of Al is 26.98 g/mol
(iii) What is ratio of free electrons/valence electrons per aluminum atom?

FCC

i) $\sigma = 3.8\times10^7$ $\quad \mu_e = 0.0012\ m^2/V\text{-}s$

$\sigma = n_e |e| \mu_e$

$3.8\times10^7 = n_e |1.6\times10^{-19}| \cdot 0.0012$

$\implies n_e = 1.98\times10^{29}$ free e^-/m^3

+8

ii) $\rho_{Al} = 2.7 g/cm^3 = 2.7\times10^6\ g/m^3$

$M_{Al} = 26.98$ g/mol

$\frac{2.7\times10^6\ g/m^3}{26.98\ g/mol} = 1\times10^5$ mol Al/m^3

$(1\times10^5$ mol Al/m$^3)(6.02\times10^{23}) = 6.02\times10^{28}$ Al/m^3

$\frac{n_e}{\#Al/m^3} = \frac{1.98\times10^{29}}{6.02\times10^{28}} =$ 3.29 free electrons/Aluminum atom

+7

iii) # valence e^- per atom: 3

$\frac{3.29}{3} =$ 1.097 free e^-/valence e^-

+5

30

4) A Si sample was found to have residual boron (B). The room temperature electrical conductivity of this Si sample with residual B was found to be 0.080 $(\Omega\text{-m})^{-1}$. B has a density of 2.34 g/cm^3. Si has a density of 2.33 g/cm^3, intrinsic conductivity of 4×10^{-4} $(\Omega\text{-m})^{-1}$, with $\mu_e = 0.19$ m^2/V-sec and $\mu_h = 0.0425$ m^2/V-sec at room temperature. Atomic weights can be found in the periodic table on the last page. Assume that B atoms substitute for Si atoms and saturation is reached.

(i) What was the *atomic%* of residual boron in this Si sample? (15 pts)
(ii) If this sample was further doped with additional 5×10^{18} m^{-3} of B atoms, what would be its electrical conductivity? (15 pts)

p-type $\quad \rho_B = 2.34\ g/cm^3 \quad \rho_{Si} = 2.33 g/cm^3$

$\sigma_{in} = 4\times10^{-4}$

$\mu_e = 0.19\ m^2/V\text{-sec}$

$\mu_h = 0.0425\ m^2/V\text{-sec}$

i) $\sigma_{doped} = 0.080$

$$\frac{\sigma_{doped}}{\sigma_{intrinsic}} = \frac{0.080}{4\times10^{-4}} = 200\times$$

$\sigma_{doped} = n_h |e| \mu_h$

$0.080 = n_h |1.6\times10^{-19}| 0.0425$

$n_h = 1.18\times10^{19}$ holes/m^3 $\Rightarrow 1.18\times10^{19}\ B/m^3$

total # atoms : use Si density

$M_{Si} = 28.086 g/mol$

$\rho_{Si} = 2.33 g/cm^3 = 2.33\times10^6 g/m^3$

$$\frac{2.33\times10^6\ g/m^3}{28.086\ g/mol} = 8.3\times10^4\ moles/m^3 = 5\times10^{28}\ Si/m^3$$

$$\text{atomic \%} = 100\left(\frac{\#\ B\ atoms}{\#\ atoms}\right) = 100\left(\frac{1.18\times10^{19}}{5\times10^{28}}\right)$$

atomic % B = 2.35×10^{-8} % ✓

ii) $\Rightarrow 1.18\times10^{19}\ B/m^3 + 5\times10^{18}\ B/m^3 = 1.68\times10^{19}\ B/m^3$

$\Rightarrow 1.68\times10^{19}$ holes/m^3

$\sigma = n_h |e| \mu_h$

$\sigma = (1.68\times10^{19})(1.6\times10^{-19})(.0425)$

$\sigma = 0.11424\ (\Omega\text{-m})^{-1}$ ✓